REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
31-08-2009	Final Performance Report	1 Sep 08 - 31 Aug 09

4. TITLE AND SUBTITLE
Detection of Humans and Light Vehicles Using Acoustic-to-Seismic Coupling

5a. CONTRACT NUMBER

5b. GRANT NUMBER
W911NF-08-1-0389

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
James M Sabatier and Alexander E Ekimov

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The University of Mississippi
PO Box 1848
University, MS 38677

8. PERFORMING ORGANIZATION REPORT NUMBER
JMS0809-02

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Army Research Office
P.O. BOX 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution Statement A: Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Heavy vehicles, such as tanks or other armored vehicles, can typically be detected using seismic sensors and sensors to detect low-frequency engine noise; light vehicles are harder to detect, particularly in high noise areas. The objective of this research effort was to conduct studies in the detection of light vehicles using sensor and signal processing techniques developed for human detection by the University of Mississippi under the MURI grant W911NF-04-1-0190. In these studies, it was found that vehicle engines and tires generated broadband sound signals from low frequencies up to ultrasonic frequencies. Ultrasonic sound signals from moving light vehicles were detected in field tests using a narrow band ultrasonic microphone. The magnitude of these signals showed dependence on the vehicle type. This research shows promise for the extension of these technologies to detect both humans and light vehicles under field conditions.

15. SUBJECT TERMS
Light vehicle detection, ultrasonic sensors, human detection

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	12	James M Sabatier
					19b. TELEPHONE NUMBER *(Include area code)* 662-915-5404

Reset **Standard Form 298** (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

DETECTION OF HUMANS AND LIGHT VEHICLES USING ACOUSTIC-TO-SEISMIC COUPLING
FINAL PROGRESS REPORT

AUGUST 31, 2009

SUBMITTED TO:

ARMY RESEARCH OFFICE
ATTN: AMSRD-ARL-RO-SS-SI (TR)
P.O. BOX 12211
RESEARCH TRIANGLE PARK, NC 27709-2211

BY:

JAMES M. SABATIER
NATIONAL CENTER FOR PHYSICAL ACOUSTICS (NCPA)
UNIVERSITY OF MISSISSIPPI
UNIVERSITY, MISSISSIPPI 38677

PERIOD: 1 SEPTEMBER 2008 – 31 AUGUST 2009
CONTRACT NUMBER: W911NF-08-1-0389
SECURITY CLASSIFICATION: UNCLASSIFIED

DETECTION OF HUMANS AND LIGHT VEHICLES USING ACOUSTIC-TO-SEISMIC COUPLING

Abstract

Heavy vehicles, such as tanks or other armored vehicles, can typically be detected using seismic sensors and sensors to detect low-frequency engine noise; light vehicles are harder to detect, particularly in high noise areas. The objective of this research effort was to conduct studies in the detection of light vehicles using sensor and signal processing techniques developed for human detection by the University of Mississippi under the MURI grant W911NF-04-1-0190. In these studies, it was found that vehicle engines and tires generated broadband sound signals from low frequencies up to ultrasonic frequencies. Ultrasonic sound signals from moving light vehicles were detected in field tests using a narrow band ultrasonic microphone. The magnitude of these signals showed dependence on the vehicle type. This research shows promise for the extension of these technologies to detect both humans and light vehicles under field conditions.

Table of Contents

List of Appendixes

Statement of the Problem Studied

Heavy vehicles, such as tanks or other armored vehicles, can typically be detected using seismic sensors and sensors to detect low-frequency engine noise; light vehicles are harder to detect, particularly in high noise areas. The objective of this research effort was to conduct studies in the detection of light vehicles using sensor and signal processing techniques developed for human detection by the University of Mississippi under the MURI grant W911NF-04-1-0190.

Technical Significance and Army Relevance

The University of Mississippi has developed acoustic/seismic methods for human detection that rely on ultrasonic sensors, but involve signal processing techniques that can combine the inputs from the ultrasonic sensors with other types of sensors such as radar or dynamic speckle sensors.

This research focuses on adapting this technology for the development of robust, smart, agile, tactical sensor technologies for the positive detection of light vehicles. Applications include line surveillance along roadways, pipelines, rivers, etc.; point surveillance at checkpoints, roadblocks, etc.; forward operating base and area surveillance; and unattended building monitoring and surveillance in urban environments. Possible deployment scenarios include the use of low-bandwidth, leave-behind sensors in restricted areas to identify intruders or snipers moving into position or full sensor suites to identify humans or vehicles approaching critical infrastructure or sensitive positions.

Summary of Important Results

This effort focused on a multi-modal sensor technology for human and light vehicle characterization using passive and active signatures. These signatures (Figure 1) are temporal signals (acoustic, video, or electromagnetic) generated by human/light vehicle movements or vehicle engine operations with specific time-frequency-amplitude characteristics [1-3]. Seismic, sound, and electromagnetic signals propagate at different speeds from an object location to a detector location. These signatures are measured by passive sensors such as geophones or accelerometers, microphones, video cameras (regular and infrared), magnetic sensors, and active Doppler radar and sonar systems. These sensors could be located at stationary positions on the ground or on moving platforms. Detection range depends on the background noise floor [4-6] and on the terrestrial environment [7]. For example, forests, buildings, or fences visually obscure human and light vehicle motion and limit the range for active Doppler radar and sonar systems due to dramatic absorption/reflection of electromagnetic/ultrasonic waves [8,9].

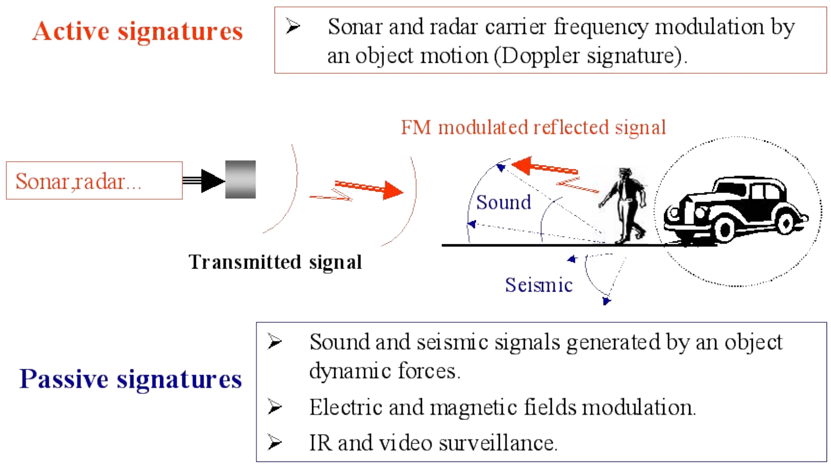

Figure 1. Human/light vehicle passive and active signatures.

Light vehicle signature study

The focus of this study was to evaluate a passive ultrasonic method for light vehicle detection. Large efforts over the past century have concentrated on reducing engine noise, vehicle vibrations, and tire noise, and have made vehicles more comfortable and less detectable for passive seismic and sound sensors.

For the heavy military vehicles, sound and seismic spectra consist mostly of harmonics caused by the engine. For these vehicles, a detection range of 100 m in the frequency band below 1 kHz was reported in Ref. [10]. Early studies of light vehicle sound signatures led to the detection of the principal spectral components of the engine noise in the frequency band below 3 kHz [3].

Broadband sound signature of a light vehicle

An initial study of light vehicle broadband sound signatures was conducted at the Army Research Laboratory's Blossom Point facility (BP) in 2007. Below, test results of sound measurements for a Chevrolet Malibu passenger car are presented. Tests were conducted for two scenarios:

- **Stop test.** The car remained in a stationary position while the engine speed was varied. This eliminated the tire noise.

- **Passby tests.** The car was driven at a constant speed first, then the engine was turned off, and the car continued moving. This eliminated the engine sound.

A PCB microphone, 377B41, with preamplifier, 426A30, and with B&K preamplifier (NEXUS) was used for broadband sound measurements. The microphone had a sensitivity of 100 mV/Pa, was operated over the frequency range from 3.15Hz-20 kHz, and had high-frequency rolloff in sensitivity above 20 kHz. This microphone was placed on the ground at 2 meters from the test

area, which consisted of a gravel road. A narrow-band microphone or ultrasonic receiver (UR) was installed 0.2 m above the ground and was co-located with the microphone. In the test configuration, the beam pattern of the UR was oriented along the gravel road. Signals from UR and the microphone were recorded and processed using a two-channel, 24-bit DAQ (Echo Indigo IO) and a laptop computer with Sound Technology software (LAB432).

Stop tests results

The spectrogram of a broadband sound signal in the frequency band of 1.3 Hz-22.05 kHz from the car in a stationary position on the gravel road a few meters from the microphone is presented in Figure 2. The sampling rate was 44.1 kHz, and the FFT size was 32,768 in this spectrogram. The test began with the engine off. The engine was turned on and idled at 800 RPM. The speed was increased to 1800 RPM, then idled at 800 RPM, then increased to 2700 RPM, and then lowered back to 800 RPM. The engine was held constant for about one minute at each speed, and then stepped to the next value. The total recording time was about 5 minutes. The car engine sound signature from the spectrogram analysis exhibited broadband frequency signals from low frequencies up to ultrasonic frequencies. Friction forces in the engine parts and the exhaust system are the sources of this broadband frequency sound signature.

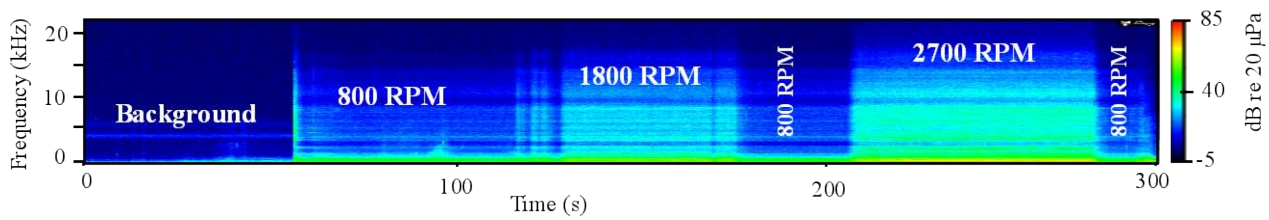

Figure 2. Spectrogram of the sound from the car in the stationary position on the gravel road in a few meters from the microphone. The sampling rate was 44.1 kHz and the FFT size was 32768.

Passby tests results

The car was tested at a set of constant speeds (30 mph, 20 mph, and 10 mph). At about 50 m from the microphone location, the engine was turned off, and the car continued moving. Eliminating the engine sound helped fulfill the goal of studying tire noise in a broadband frequency range from a moving vehicle. Spectrograms of the car passby tests are presented in Figs. 3(a)-2(c). At the closest point of approach (CPA) at 2 m from the gravel road, the sound signal had a broadband frequency response up to ultrasonic frequencies. The magnitude of the tire sound signal depended on the speed of motion. At the lowest speed (10 mph), the high frequency sound from tires was less detectable than at the highest speed (30 mph).

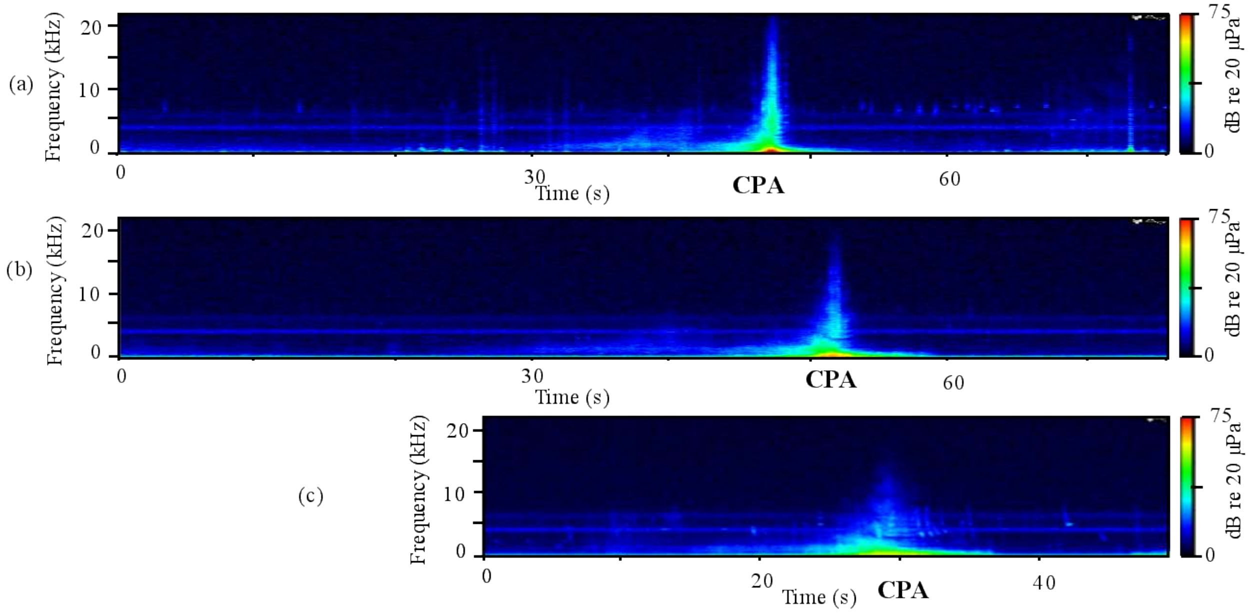

Figure 3. Spectrogram of the sound from the car moving on the gravel road with the engine turned off. The speeds of car motion before the engine was turned off were: (a) 30 mph, (b) 20 mph, and (c) 10 mph. The sampling rate was 44.1 kHz and the FFT size was 32768.

Multiple vehicle detection with an ultrasonic sensor

Vehicle engines and tires all generated broadband sound signals. The next experiments demonstrated the ability to detect light vehicles using a narrow-band ultrasonic microphone operated in the frequency band of 25-26 kHz. In the spectrograms in Figs. 4 (a) and 3(b), the results of passby tests for two SUVs (Chevrolet Suburban and Chevrolet Tahoe), a van, and a Humvee are presented. The UR was installed 0.2 m above the ground and 2 m from the gravel road, and the beam pattern of the UR was oriented along the gravel road.

In the first test, the SUVs (Chevrolet Suburban and Chevrolet Tahoe) were moving one behind the other on the road with a constant speed of 15 mph [Fig. 4(a)]. In the second test, a van and a Humvee were moving in the same manner with a constant speed of 20 mph.

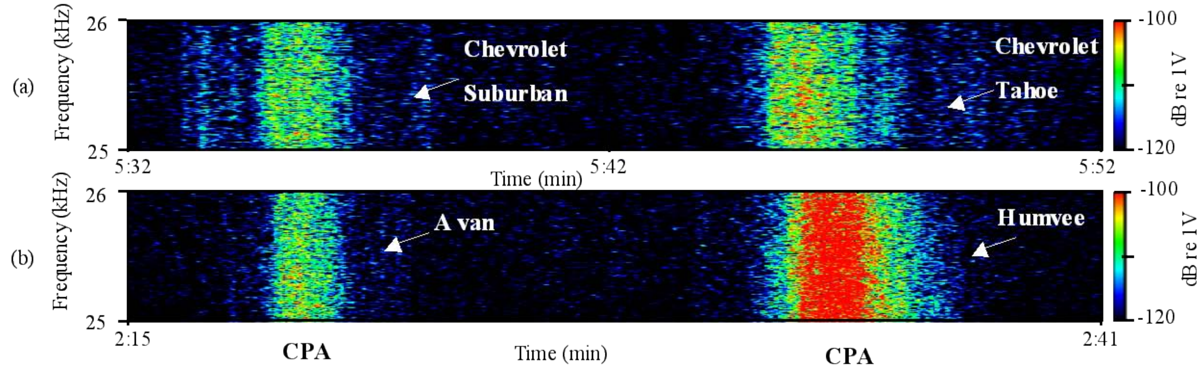

Figure 4. Spectrograms of the ultrasonic signals from vehicles moving on gravel road. (a) Two SUVs at 15 mph (Chevrolet Suburban and Chevrolet Tahoe), (b) A van and a Humvee at 20 mph. The sampling rate was 44.1 kHz and the FFT size was 32768.

The light vehicles' ultrasound signatures from the spectrogram analysis exhibit detectable ultrasound signals at the CPA for all tested vehicles. The magnitude of these signals depended on the vehicle type. As follows from Fig. 4(b), the magnitude of the ultrasonic signal generated by the Humvee was greater than the signal generated by the van.

References

1. F.W. Galbraith and M.V. Barton, "Ground Loading from Footsteps," J. Acoust. Soc. Am. 48 (5) (Part2), 1288-1292 (1970).
2. A. Ekimov, and J. M. Sabatier, "Vibration and sound signatures of human footsteps in buildings," J. Acoust. Soc. Am., 120(2), 762-768, (2006).
3. R. Hickling, L.N. Bolen, R.F. Schumacher, "Indoor system for efficient measurement of the sound power of light vehicle and for noise-control diagnostics," SAE Technical Paper Series 891145, 193-209 (1989).
4. J. M. Sabatier, and A. E. Ekimov, "Range limitation for seismic footstep detection," Proc. SPIE, 6963, 0V-1-OV-12, (2008).
5. A. E. Ekimov and J. M. Sabatier, "Human detection range by active Doppler and passive ultrasonic methods," Proc. SPIE, 6943, OR-1-OR-8 (2008).
6. J. M. Sabatier, A. E. Ekimov, "A review of human signatures in urban environments using seismic and acoustic methods," Proc. IEEE, Proc. Int. conf. Technologies for Homeland security, 215-220 (2008).
7. A. Ekimov and J. M. Sabatier, "Orthogonal sensor suite and the signal-processing algorithm for human detection and discrimination", Proc. SPIE 7303-19, (2009).
8. James M. Sabatier, Alexander E. Ekimov, and Richard A. Mack, "Stand-Off Measurement of a Vehicular Acoustic Signature Using Natural Microphones", Proc. of the Military Sensing Symposium on Battlespace Acoustic and Seismic Sensing, Magnetic and Electric Field Sensors, 11 pp. (2007).
9. Vyacheslav Aranchuk, Alexander E. Ekimov, and James M. Sabatier, "Standoff detection of obscured vehicle with laser Doppler vibrometer," Proc. SPIE 7303-16, (2009).

10. J. Altmann, “Acoustic and seismic signals of heavy military vehicles,” Journal of Sound and Vibration 273, 713–740 (2004).

Appendix A

Program Statistics

(1) Submissions or publications under ARO sponsorship. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals – 0
(b) Papers published in non-peer-reviewed journals – 0
(c) Presentations

(i) Presentations at meetings, but not published in Conference Proceedings – 0
(ii) Non-peer-reviewed Conference Proceeding publications – 2

Alexander E. Ekimov and James M. Sabatier, "Orthogonal sensor suite and the signal-processing algorithm for human detection and discrimination," Proc. SPIE Vol. 7303, DOI 10.1117/12.818823 (2009)

Alexander Ekimov and James M. Sabatier, "Human motion characterization," Human, Light Vehicle and Tunnel Detection Study Group, Army Research Laboratory, June 16-17, 2009

(iii) Peer-reviewed Conference Proceeding publications – 0

(d) Manuscripts – 0
(e) Books – 0
(f) Honors and awards – 0
(g) Titles of Patents Disclosed during the reporting period – 0
(h) Patents awarded during the reporting period – 0

(2) Student/Supported Personnel Metrics**.**

(a) Graduate Students -1
(b) Post Doctorates - 0.
(c) Faculty -0.
(d) Undergraduate Students -0.
(e) Graduating Undergraduate Metrics – Not applicable
(f) Master's degrees awarded – 0
(g) Ph.D.s awarded – 0
(h) Other research staff –
(i) James M. Sabatier, Principal Scientist, 9% FTE
(ii) Thomas G. Muir, Principal Scientist, 3% FTE
(iii) Alexander E. Ekimov, Senior Research Scientist, 24% FTE
(iv) Ina Aranchuk, Associate Research & Development Engineer, 7% FTE

(3) Technology Transfer

- Publications and Professional Meetings
  - SPIE Defense and Security Symposium
- US Armament Research, Development, and Engineering Center (ARDEC) involved in signal processing research
- Joint data collection exercises with ARDEC and ARL in October 2008 and with ARDEC in May 2009
- Proposal submitted to ARDEC for continued research in human and light vehicle detection
- UM-led working group conducted first meeting at ARL in June 2009 on human, light vehicle, and tunnel detection. 49 participants from academia, industry, and government organizations. Included are 12 international participants
- Dr Sabatier selected for an IPA assignment to ARL for research in human, light vehicle, and tunnel detection